ALUMINUM GALLIUM NITRIDE/GALLIUM NITRIDE HIGH ELECTRON MOBILITY TRANSISTORS

FIELD OF THE INVENTION

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 61/136,793, filed on Oct. 3, 2008, and entitled METHOD OF CREATING BACK BARRIER, AND ENHANCING THE OFF-STATE BREAKDOWN AND BLOCKING CAPABILITY IN AlGaN/GaN HEMT BY FLUORINE ION IMPLANTATION, the entirety of which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The subject disclosure is directed to field effect transistors and, more specifically, to structures, devices, and methods for creating a back barrier and enhancing off-state breakdown and blocking characteristics in Aluminum Gallium Nitride/Gallium Nitride (AlGaN/GaN) High Electron Mobility Transistors (HEMTs) by fluorine ion implantation.

BACKGROUND OF THE INVENTION

[0003] High Electron Mobility Transistors (HEMTs), also called heterostructure field-effect transistors (HFETs) or modulation-doped field-effect transistors (MODFETs), are field effect transistors typically incorporating a junction between two materials with different band gaps, e.g., a heterojunction, as the channel instead of a doped region. HEMTs use high mobility electrons generated by a heterojunction comprised of a highly-doped wider-bandgap n-type donor-supply layer, or unintentionally doped Aluminum-Gallium-Nitride (AlGaN), for example, and a non-doped narrower-bandgap layer with little or no intentional dopants, e.g., Gallium-Nitride (GaN).

[0004] For example, electrons generated in an n-type donor-supply layer can drop into the non-doped narrower-bandgap channel at the heterojunction to form a thin depleted n-type donor-supply sub-layer and narrower-bandgap channel, due to the heterojunction created by different band-gap materials forming an electron potential well in the conduction band on the non-doped side of the heterojunction. In the framework of AlGaN/GaN heterostructures, there is often no dopant required in the AlGaN layer due to the strong spontaneous and piezoelectric polarization effect in such systems. For example, electrons from surface donors can be swept into the GaN channel by the intrinsic polarization induced electric field. In this instance, the electrons can move quickly without colliding with any impurities, due to the unintentionally doped (e.g., not intentionally doped) layer's relative lack of impurities or dopants, from which the electrons cannot escape. The net result of such a heterojunction is to create a very thin layer of highly mobile conducting electrons with very high concentration or density, giving the channel very low resistivity. This layer is known as a two-dimensional electron gas (2DEG). As can be expected in field-effect transistor (FET), voltage applied to the gate alters the conductivity of this layer to form transistor structures.

[0005] One kind of high-electron mobility transistor (HEMT) including Gallium Nitride is known as an Aluminum Gallium Nitride/Gallium Nitride (AlGaN/GaN) HEMT, or an AlGaN/GaN HEMT. Typically, AlGaN/GaN HEMTs can be fabricated by growing crystalline films of GaN, AlGaN, etc. on a substrate (e.g., sapphire, silicon (Si)(111), silicon carbide (SiC), etc.) through an epitaxial crystal growth method (e.g., metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), etc.) and processing the epitaxial substrate thus grown, to form the desired structures.

[0006] Recently, AlGaN/GaN HEMTs have received attention for their ability to operate at high voltage and high current levels, which results in enhanced high-power performance, as a benefit of the inherent high-density 2DEG, high electron mobility, and high critical breakdown electric field. As a consequence, the wide bandgap AlGaN/GaN HEMTs are emerging as excellent candidates for next-generation radio-frequency (RF) and microwave power amplifiers. One important operational and design parameter of field-effect transistors (FETs) generally and HEMTs in particular is the off-state breakdown voltage (BV_{off}), because it determines the maximum output power for class A operation.

[0007] However, reported off-state breakdown voltage values still remain significantly below the theoretical limit for such devices. For instance, current injected from the source to the drain, resulting from unintentional n-type background doping (e.g., due to intrinsic nitrogen vacancies or oxygen impurities) in the unintentionally doped GaN (i-GaN) buffer layer, has been shown to be one of the main factors that limit the breakdown voltage in practical devices. It has been shown that drain induced barrier lowering (DIBL) in the GaN buffer layer worsens at greater depths from the 2DEG channel, for example, due to the low barrier of the GaN buffer layer. As a result, it is expected that electrons can be injected from the source to the high-field region through the buffer and initiate impact ionization in the channel at large drain bias and cause the premature three-terminal off-state breakdown of the device before gate breakdown.

[0008] While a general reduction in n-type background doping in the unintentionally doped GaN buffer layer has been attempted, such efforts have typically proved to be difficult and commercially unviable. Additionally, intentional incorporation of deep acceptor levels in the GaN buffer layer by doping with carbon (C) or iron (Fe) traps electrons and causes current collapse in the HEMT device as well as large hysteresis current-voltage (I-V) output characteristics of the devices, while also potentially causing permanent contamination of the growth system. In addition, these acceptors may cause device instability, especially at high drain voltage. It is thus desired to improve the breakdown voltage characteristics in practical HEMT devices.

SUMMARY OF THE INVENTION

[0009] The following presents a simplified summary of the specification in order to provide a basic understanding of some aspects of the specification. This summary is not an extensive overview of the specification. It is intended to neither identify key or critical elements of the specification nor delineate any scope particular to any embodiments of the specification, or any scope of the claims. Its sole purpose is to present some concepts of the specification in a simplified form as a prelude to the more detailed description that is presented later.

[0010] In various embodiments, enhanced back barrier (EBB) structures and devices are provided that improve the off-state breakdown and blocking characteristics in Group III-Nitride HEMTs in general, and AlGaN/GaN HEMTs in particular, by creating higher energy barriers at the back of the 2DEG channel in the unintentionally doped GaN buffer.